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Exploring the Effect of the Fog of War on the Value of Competitive Edges in Land Warfare

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All other things being equal, possessing a competitive edge over one’s adversary in a given component of land warfare is usually thought to translate into improved combat effectiveness. A common assumption is that information is the critical component in which to achieve this. Little is known quantitatively about the robustness of the above two statements to variations in the level of battlefield uncertainty (the so-called fog of war).

Recently, other researchers performed experiments using a modified version of chess to test these hypotheses. This paper outlines our attempt to repeat the chessboard experiments using another analogue of warfare based on a computer cellular automata model known as ISAAC. The benefits of doing this include the reduction in uncertainty and output variations by using less subjective players; the ability to obtain more accurate statistics from increased sampling; the capacity to consider more parameter excursions and scenarios, leading to further hypothesis testing; and importantly to test whether the chessboard conclusions are either model or scenario dependent.

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Background

- Swedish National Defence College experiments:
  - Is the absolute level of uncertainty about the situation in the battlespace important?
  - Chess based wargame
  - Value of information, strength and tempo superiority for different levels of uncertainty
- Conclusions
  - Information superiority more important where uncertainty is low
  - Tempo superiority more resistant to uncertainty than information or strength superiority

Recently, three researchers, Jan Kuylenstierna, Joacim Rydmark and Tonie Fahraeus, from the Swedish National Defence College conducted experiments using a modified version of chess to explore some of the implications that increases in the level of battlefield uncertainty plays on the robustness of various forms of superiority.

The question, or hypothesis, they were interested in testing is ‘whether the absolute level of uncertainty about the situation in the battlespace is important’ as opposed to the relative level.

The experiment was set up with a each player using a separate chess board with a screen in between them. A third (impartial) person would make the corresponding move on the opponents board. Uncertainty was then modelled using a time lag – that is, players could only see their opponent’s move x time steps ago (with low values of x corresponding to minimal uncertainty).

Three edges or superiorities were modelled and analyses. These were, an information edge, which was provided by letting one player see the opponent’s move earlier than they saw their move; a strength edge, which was provided by removing some pieces from one player’s board at the start; and a movement edge, which was provided by allowing one player to make two moves while the opponent made one.

Two general conclusions were made from this study. The conclusion of interest to our study was that tempo was the edge that was more robust to the level of battlefield uncertainty and hence would be that most sought after.

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This Experiment

- Use another analogue of warfare: ISAAC
  - Cellular Automata
  - Agent based
  - Distillation
- Advantages
  - Data farming
    - PC
    - MHPCC – Typhoon (~150 CPU's)
  - Less 'subjective' players
- Test robustness of chess board experiments

As mentioned before, this paper outlines our attempt to repeat the chessboard experiments using another analogue of warfare based on a computer cellular automata model known as ISAAC. ISAAC (Irreducible Semi Autonomous Adaptive Combat) model was a proof of concept model developed by Center for Naval Analyses (CNA) as part of US Marine Corps Combat Development Command's Project Albert. Agent based distillations are low-resolution abstract models, used to explore questions associated with land warfare in a short period of time.

Being agent based means that only simple behavioural rules need to be assigned. Thus the scenario is generally much less scripted than that required of traditional wargames, the idea being that higher level behavior is allowed to develop, or emerge, from the dynamic local interaction of the entities on the battlefield. This approach allows greater freedom of action within the scenario, which appears to be suitable for more modern warfare which rely more and more on manoeuvre concepts.

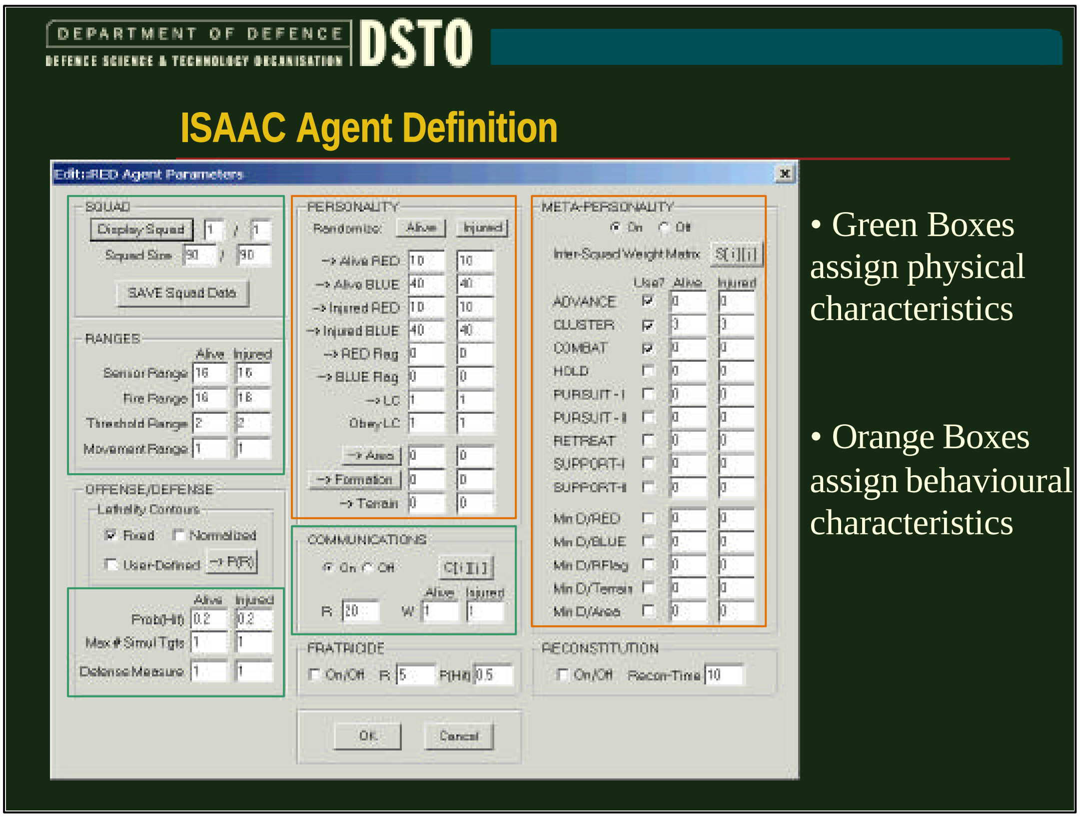
Being deliberately low-resolution means that the detailed physics of combat are largely ignored (or abstracted to simple constructs). This allows a focusing of thought on the essential elements of the analysis, which typically is the dynamic interaction of entities on the battlefield.

The two characteristics above then allow a significant amount of data generation and analysis (called data farming) to be performed in a relatively short period of time. This allows extensive parameter excursions to be performed, both in terms of variations in platform capabilities (physical characteristics) and tactics (behavioural characteristics), from the baseline scenario. This then enables one-way and two-way sensitivity analyses to be performed with statistically significant data to explore any non-linear behaviour or synergies in the system. Another benefit of this approach is the reduction in uncertainty and output variations by using 'less subjective players'. This is in stark contrast with the chessboard experiments, where humans were used to generate the results.

Robustness – Wanted to test robustness of chess board experiment for different scenarios and different surrogates for uncertainty.

to test whether the chessboard conclusions are either model or scenario dependent

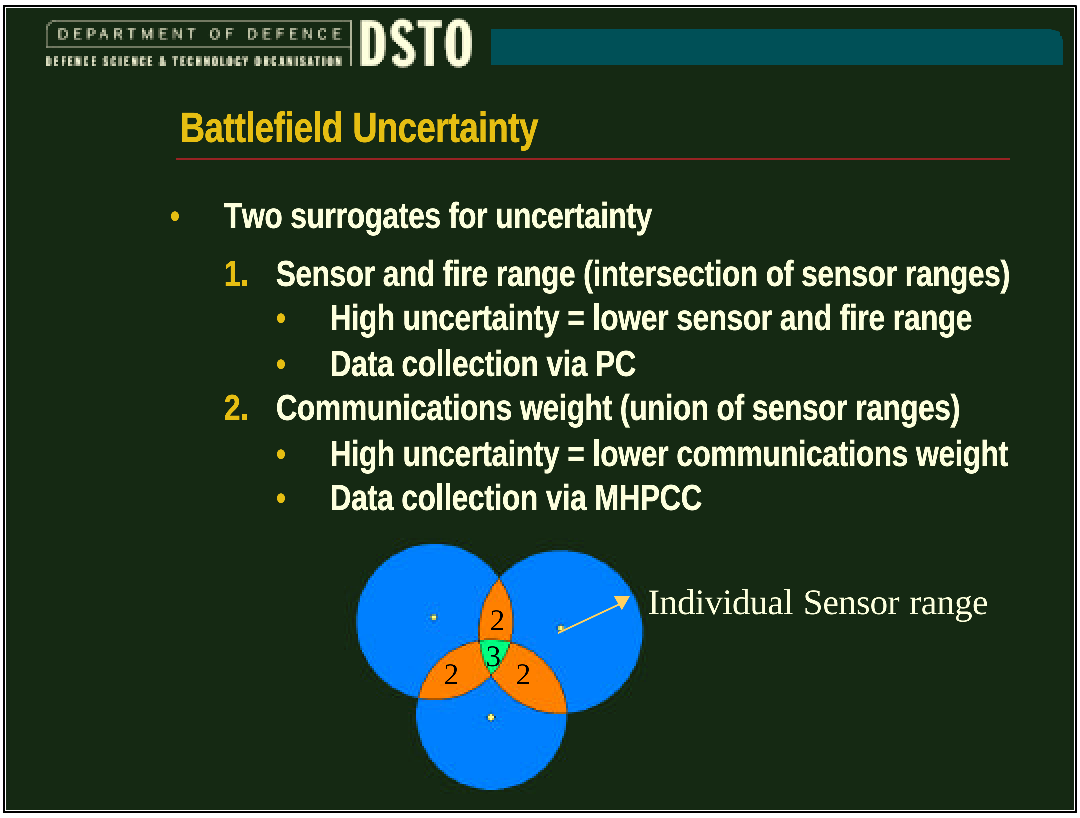
The Maui High Performance Computing Centre is managed by the University of New Mexico and was funded by the US Department of Defense. It's computational resources total 1,399 processors running at a theoretical peak performance of 1.8 teraflops (trillion floating point operations per second). I also has 668 gigabytes of memory, 8 terabytes of disk storage and 20 terabytes of high performance tape storage.



This shows the relative simplicity in defining entities or agents within ISAAC. The column on the left defines the physical performance characteristics of the entity (sensor, weapons, movement, force size). The second column assigns a personality profile to the entity. ISAAC has default built in rules that specify how agents act in a generic environment. An ISAAC entity has a six-element personality weight vector. Positive weights indicate tendency to move towards the appropriate entities while negative values indicate tendency to move away from the specified entities. The proper choice of relative weightings in this column allows one to define the behavioural characteristics of the entity being modelled.

For example, to simulate say reconnaissance behaviour in an Army unit, ‘negative attractiveness’ to friendly and enemy entities are used. The former is used to create a dispersed reconnaissance force, while the latter is used to ensure the reconnaissance entities do not become decisively engaged themselves. A high attractiveness to the Area entity is used to simulate an area of operations (AO) assigned to the reconnaissance entity.

The final column is used to simulate exceptions or extensions to the default personality defined by the second column. For example, the Cluster ‘meta-personality’ is used to further enhance the dispersed nature of the reconnaissance force, as are the Minimum distance to friendly and enemy parameters.



As mentioned before, the chessboard experiment utilised a surrogate for battlefield uncertainty whereby each players knowledge of the location of the opposing forces was delayed by a certain number of moves. Although desirable (in order to closely match their experiment) it was not possible to implement this feature in ISAAC. Thus, instead we examined two alternative surrogates for battlefield uncertainty. This has the advantage of comparing the two experiment's results across these surrogates as well as the model of warfare used.

The first surrogate used was that increased battlefield uncertainty corresponded to decreasing sensor and fire (or weapons) ranges of the individual ISAAC entities. This intuitively feels right if one takes the fog of war literally. It differs from the Swedish experiment in that here, the exact location of some proportion of the oppositions forces is known, whereas in their experiment the approximate (based on where they were exactly some time ago) location of all of the opposition forces was known.

For the experiment runs using this surrogate, the data was generated using the PC version of the model.

The second surrogate was proposed after some thought was given to the mechanisms by which the collection of entities would utilise the lower levels of uncertainty (via their increased sensor and weapon ranges). It is generally held that the ability to coordinate action and concentrate force at the correct time is an important factor in generating combat effectiveness. The mechanism to allow this coordination of action between entities within ISAAC is by shared knowledge of the location of the opposition forces.

Under the first surrogate for battlefield uncertainty, this knowledge sharing will only take place when an opposing entity is jointly within the sensor ranges of two or more entities – that is their intersection, and as can be seen diagrammatically the proportion or probability of coordinated action by two, three or more entities is relatively small. Taking this diagrammatic argument further then, it would appear that improved levels of coordination may result if the knowledge sharing was over the union of the individual sensor ranges. This can be reasonably easily modelled by the use of the communications feature of ISAAC, that is the information of the opposition's locations contained in one entity is communicated to others.

Thus, the second surrogate used was that increased battlefield uncertainty corresponded to decreased weighting to the communicated detections. This indicates the degree to which each side can use information about the opposing forces disposition.

For the experiment runs using this surrogate, the data was generated using the facilities at the MHPCC.

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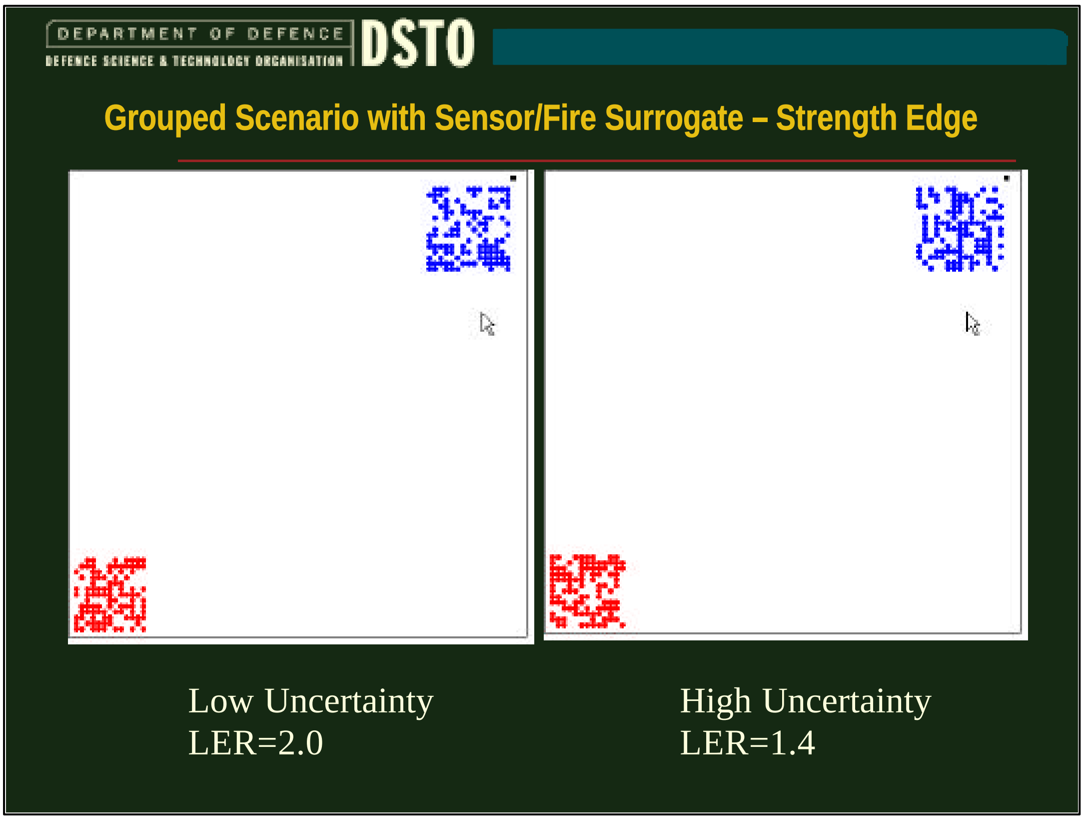
Experiments

- Two Scenarios
  - Dispersed
  - Grouped
- Edges
  - Information - Blue twice sensor/comms range of Red
  - Movement - Blue twice speed of Red
  - Strength - Blue 10% more entities than Red
- Measure of Effectiveness -- Loss Exchange Ratio

Two scenarios were played in this experiment – a dispersed scenario and a grouped scenario. This was performed to examine the robustness of the results to scenario variations. It was also conducted since chess would appear to sit perhaps between these two extremes and we wish to contrast across the experiments.

We attempted to examine the same three edges or superiorities that the chessboard experiment examined – information, tempo and strength. Strength and tempo (or movement) could be modelled in very similar ways. However, the information edge was related to the uncertainty surrogate (information lag in theirs and sensor or communications range in ours) so that the correlation was not as close, and should be considered when analysing the results.

The measure of effectiveness in chess is ultimately checkmate or resignation although this is more often that not very closely correlated with the relative strengths remaining (a queen sacrifice to force mate in two moves being one exception!) In land warfare, a traditional and generally accepted measure of effectiveness is the Loss Exchange Ratio, which is defined as the number of opposition losses divided by the number of own losses. Thus a LER greater than one indicates better performance. Thus, the MOE used in both experiments are very closely related.

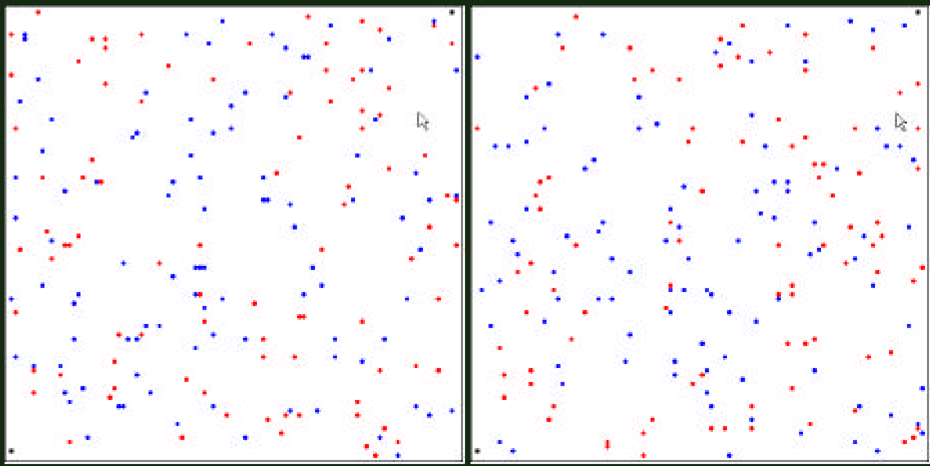


In both scenarios each team's objective is to reach the opponents flag with minimal casualties.

In the first scenario there is minimal uncertainty. As a result both squads know the location of their opponent's while still a fair distance away from them. Initially both squads stand off from the other to avoid contact. Once red realises they are facing a larger blue force their reaction is to retreat. Blue on the other hand senses their numerical advantage and advances to eventually overcome red.

The first point to notice in the second scenario is that before the two squads even meet both squads break up in to several smaller squads. This is a consequence of having a smaller sensor range and hence a higher level of uncertainty as to where other friendly agents are. When the two squads meet the battlefield contains a number of smaller, localised skirmishes. This gives red a better opportunity to at least win some of the small battles and hence the lower loss exchange ratio.

Dispersed Scenario with Sensor/Fire Surrogate – Strength Edge



Low Uncertainty
LER=1.3

High Uncertainty
LER=1.3

In these dispersed scenarios the objective is to occupy as much of the battlefield as possible.

Both these examples seem to suggest that a strength edge isn't as important in this dispersed scenario as it was in the grouped scenario. The logical explanation for this is that initially all agents are forced to act individually and not as a group. As time progresses agents locate the whereabouts of other friendly agents and are drawn to them. Again this results in a series of local skirmishes. This means that blue is not guaranteed to have a strength edge at all of the local battles which ensures that some local battles are won by red and some by blue.

When uncertainty is low both sides are able to locate other friendly agents quickly and the overall length of the scenario is much shorter than for higher levels of uncertainty.

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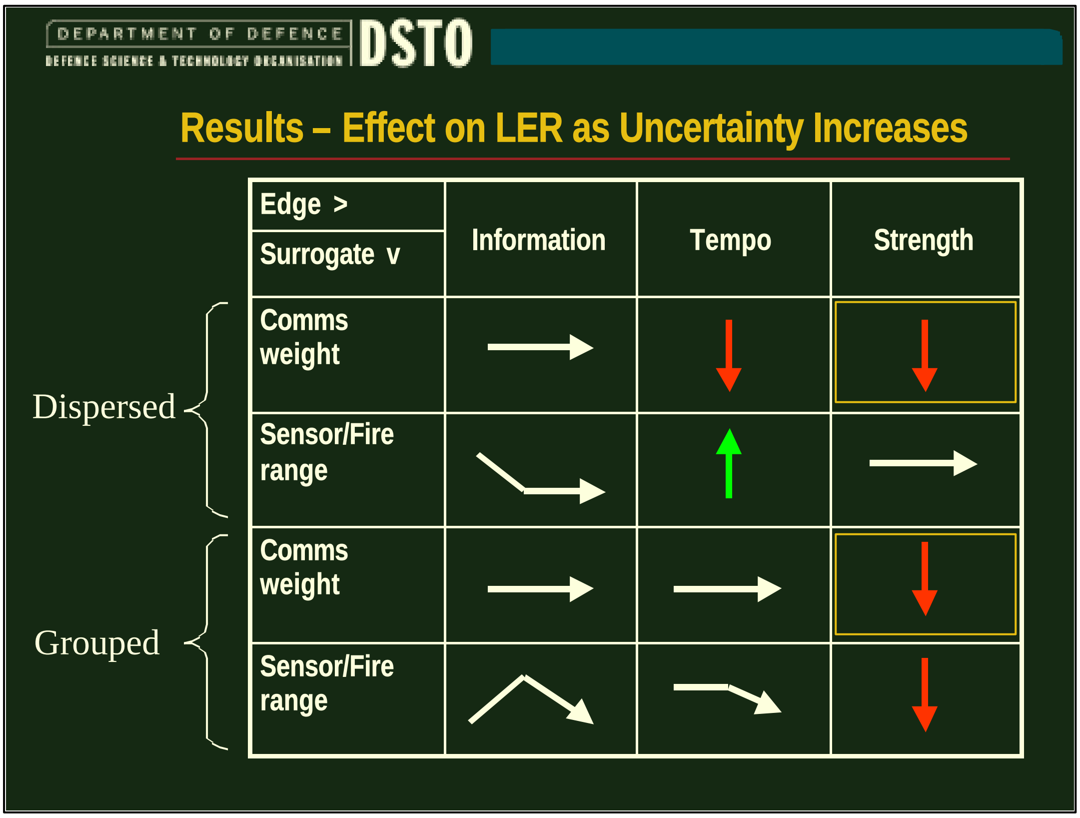
Results – Effect on LER as Uncertainty Increases

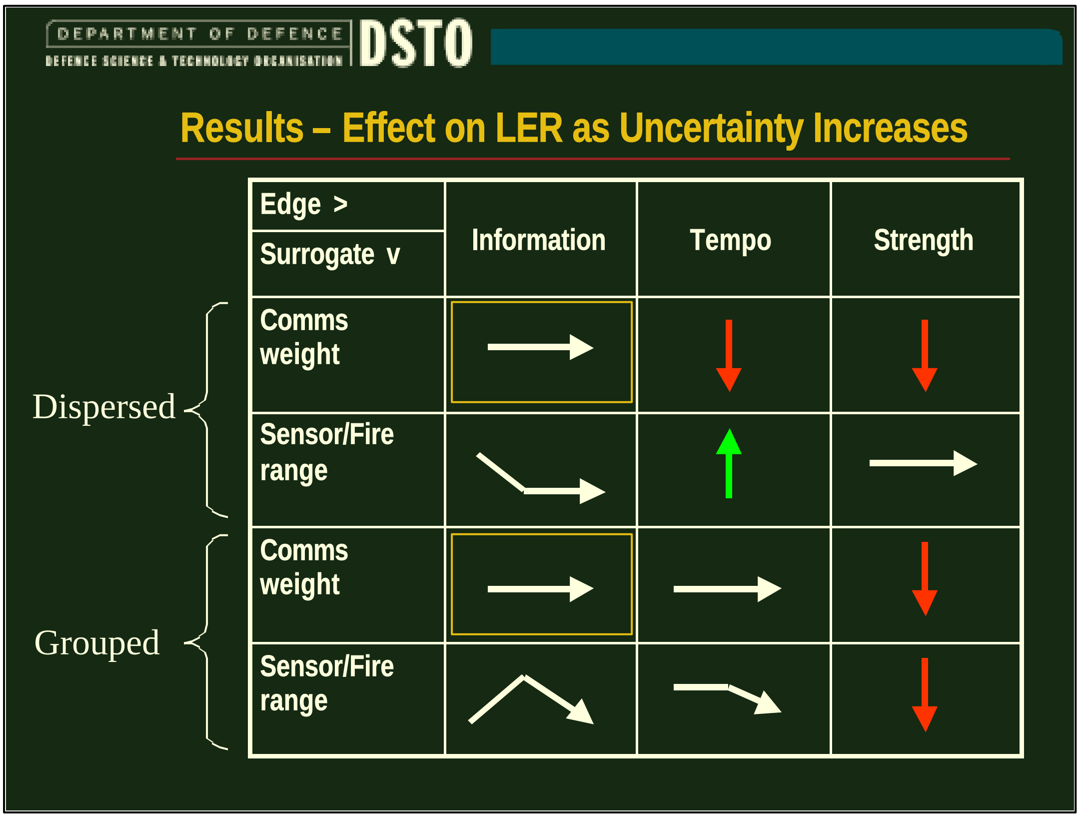
	Edge > / Surrogate v	Information	Tempo	Strength
Dispersed	Comms weight	→	↓	↓
	Sensor/Fire range	↘→	↑	$\boxed{\rightarrow}$
Grouped	Comms weight	→	→	↓
	Sensor/Fire range	↗↘	→↘	$\boxed{\downarrow}$

This table allows us to compare edge, surrogate and scenario dependencies and robustness. The direction of the arrows indicate the effect on the LER as the level of uncertainty increases.

Highlighted boxes are the examples shown earlier where we saw the LER remain constant for the dispersed scenario but decrease for the grouped scenario. This suggests that the effect of the strength edge using the sensor/fire surrogate for uncertainty is scenario dependent.



However, if we compare the same scenarios when the communications weight surrogate is used we find that the effect of having a strength edge is independent of the choice of scenario.



This is also the case for the information edge and the communications surrogate.

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Results – Effect on LER as Uncertainty Increases

	Edge > / Surrogate v	Information	Tempo	Strength
Dispersed	Comms weight	→	↓	↓
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Grouped	Comms weight	→	→	↓
	Sensor/Fire range	↗↘	→↘	↓

If we instead keep the scenario fixed and vary the surrogate we see that for dispersed scenario the strength edge LER is dependent on the surrogate being used.

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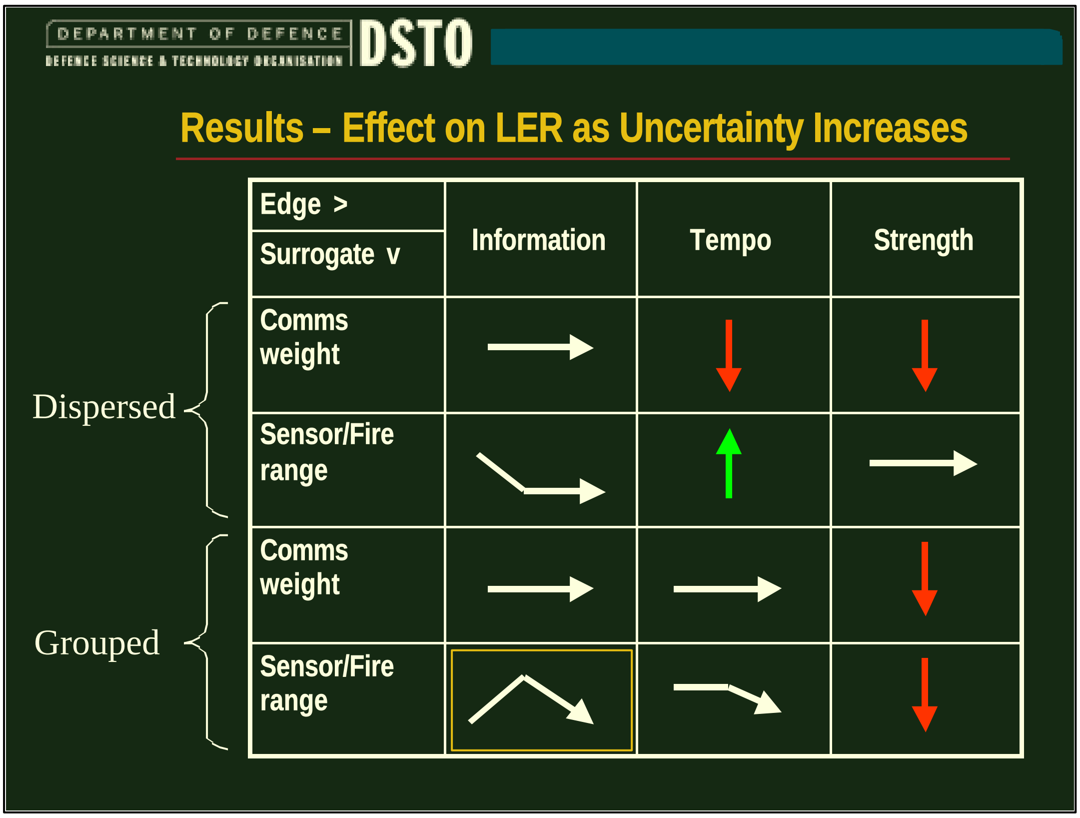
Results – Effect on LER as Uncertainty Increases

	Edge > / Surrogate v	Information	Tempo	Strength
Dispersed	Comms weight	→	↓	↓
	Sensor/Fire range	↘→	↑	→
Grouped	Comms weight	→	→	↓
	Sensor/Fire range	↗↘	→↘	↓

However the grouped scenario is independent of the surrogate.



This example is the only case where there appeared to be any sort of local maxima or minima. This may suggest that up until a certain level of uncertainty it is advantageous to have an information edge and beyond that point it may be better to seek perhaps a tempo edge.

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Conclusions

- Strength edge generally degrades with uncertainty
- Tempo edge robust for grouped scenario but surrogate dependent otherwise
- Information edge robust for communications surrogate but possible local optimum otherwise
- Surrogate used is important in dispersed scenarios
- Battlefield uncertainty more complex than single surrogate

Based on these results, we can begin to make some conclusions concerning the three edges and their robustness to the level of battlefield uncertainty, the uncertainty surrogate used, and the type of scenario being played. In doing so, we can then make some comparisons with the results and conclusions from the Swedish chessboard experiments.

As mentioned before, the strength and tempo edges were more closely modelled to the chessboard experiment than the information edge. Concerning the strength edge, the results of our ISAAC experiments appear to correlate well with the chessboard experiment, that is as the level of battlefield uncertainty increases the value of an initially superior weight of force diminishes. This conclusion appears to be robust across both the scenario played and the uncertainty surrogate used.

Concerning the tempo edge, the results of our ISAAC experiment appear to partially correlate with the chessboard experiment, in that this edge appears to be robust to battlefield uncertainty but only for the grouped scenario. For the dispersed scenario the results then depend on the uncertainty surrogate used. One could speculate perhaps that this suggests that chess is an example of a grouped scenario.

As mentioned above, the information edge was less well matched between experiments and the results reflect this. However, from our ISAAC experiment we can draw the observation that an information edge (based on the communications surrogate) also appears to be robust to both battlefield uncertainty and scenario. This result is contrary to the chessboard experiment, in which the value of an information edge degraded with battlefield uncertainty. With the sensor surrogate for uncertainty, the results here also appear to suggest that an optimum level of uncertainty (not equal to the minimum) may exist. This is again somewhat counter-intuitive whereby one would suspect that minimum battlefield uncertainty should provide the best utility.

The results also suggest that the surrogate used for battlefield uncertainty is more important in dispersed scenarios than in grouped scenarios. It is of course impossible to say which surrogate is correct, or even which is more closely representative of battlefield uncertainty. What can be said is that battlefield uncertainty is a more complex concept than that which allows representation by simple surrogates, and that the conclusions based on a single surrogate (as in the chessboard experiments) should be tested and contrasted with others (as we have attempted here).

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Future Work

- Other surrogate experiments:
  - Short sighted chess
  - Friction and Local Commander Parameters
  - High resolution models (wargames)
- Other edges – e.g. lethality, 'braveness'
- Improved statistical analysis
  - Significance tests
  - Experimental design

It should be emphasised that the results presented here are not to be taken as definitive, but rather as providing further information or evidence to support analysis of the effect of battlefield uncertainty (the fog of war) in land warfare. To support this effort further, various avenues of futu re work should be pursued. A theme that has emerged from this presentation is the need to consider various surrogates for battlefield uncertainty.

Three which are of immediate interest to us are (a) short sighted chess, whereby uncertainty is not modelled by complete information lags, but rather by immediate sensor limitations in much the same was as is modelled in ISAAC; (b) using the command and control structure within ISAAC and a concept of friction which binds subordinates to the local commander; and © using higher resolution models of warfare. The drawback of this last suggestion is the overhead in setting up the scenario (which can have timeframes measured in weeks) and generating the results (which can have timeframes measured in days).

We have attempted to repeat the chessboard experiment and therefore have only concentrated on examining the three edges of information, tempo and strength. There are a number of other edges that could be explored, two of which might include lethality (a physical characteristic) and braveness (which could be approximated with behavioural surrogates).

Finally, the results presented here have in the main been based on an examination of the mean value of the distributions. One should utilise more stringent statistical tests of these means, which would allow more rigorous hypothesis testing. Improved statistical analysis might also suggest improved experimental designs, such as factorial designs to reduce the computational effort required for analysis.